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LABORATORY IN SPACE

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Introduction

In spite of the very general interest in hypervelocity and space flight actual participation in the work has been limited by the usual shortages of money and facilities. I have undertaken in this report, therefore, to discuss a current program which is not only of intrinsic technical interest, but also provides opportunities for more general participation. For reasons which will become obvious this is called the piggyback program. In our organization it is also known as the Space Laboratory Program.

To promote a missile system to operational status, a significant number of check-out flights must be scheduled. Since the check-out gear may not weigh as much nor occupy as much volume as the design payload, it is most reasonable to consider a working ballast. Provided that the primary flight objectives are not compromised, we are presented here with an opportunity to use the flight as an experimental facility. The capabilities of this facility are in many respects altogether unique. In addition, certain types of experiment which might be done in other ways may be more easily, conveniently, or cheaply performed piggyback.

The particular work that will be discussed here was conducted in connection with the THOR and ATLAS nose cone programs by the General Electric Company, Missile and Space Vehicle Department, under the sponsorship of the Air Force Ballistic Systems Division and in association with other firms and agencies in the space technology field. Data on a wide variety of problems have been obtained and a number of notable space "firsts" have been scored. These results are in a sense an extra dividend from the investment in the nose cone program.

Since the boosters, vehicles, telemetry links, and in some cases, the recovery systems are paid for by the Air Force, the Space Lab experimenter can operate at modest cost. After he has convinced the Air Force of the pertinence of his program, he need only observe limitations of size, weight, configuration and power availability and his instruments are carried as a package within the vehicle.

The experiments involve the cooperation of many people and organizations. I have elected to give incomplete citations rather than none. The over-all program was reviewed in 1959 in two separate articles (1) (2). Some parts of the program have already been discussed in the literature. In certain other cases data have been transmitted from General Electric to the experimenter and the publication status is not known.

Before discussing the particular experiments that have been performed so far, some of the details of the experimental facility will be described.

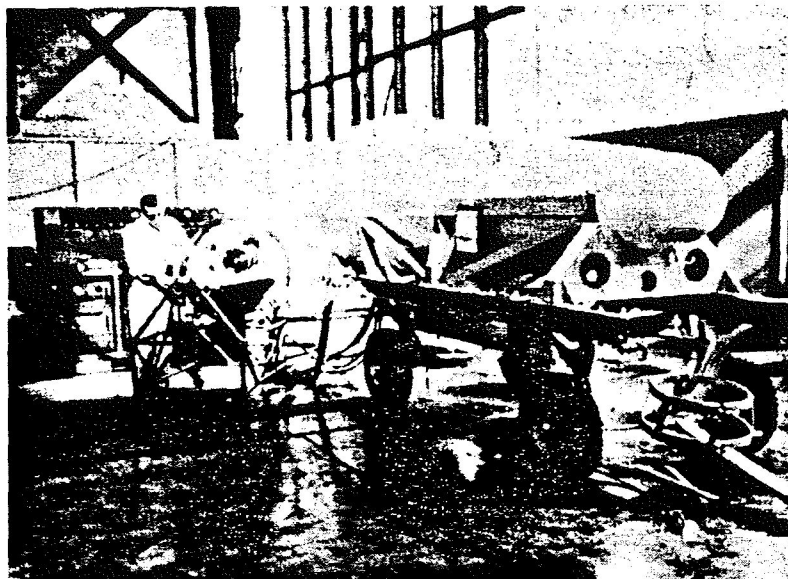


Fig. 1

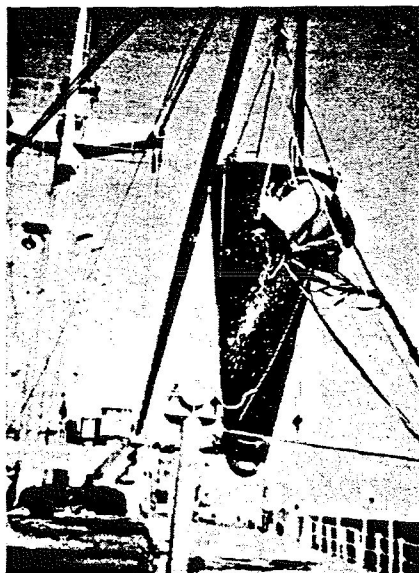


Fig. 2

Photographs of a typical recoverable vehicle, the RVX-2A, before and after flight are shown in Figs. 1 and 2. This vehicle is about twelve feet long and about five feet in diameter across the base. It has a gross weight of about 3000 pounds. This particular vehicle has been exhibited publicly and some of you may have seen it.

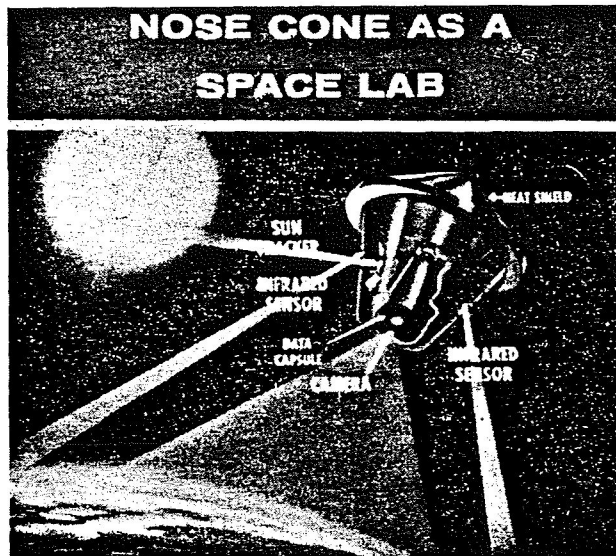


Fig. 3

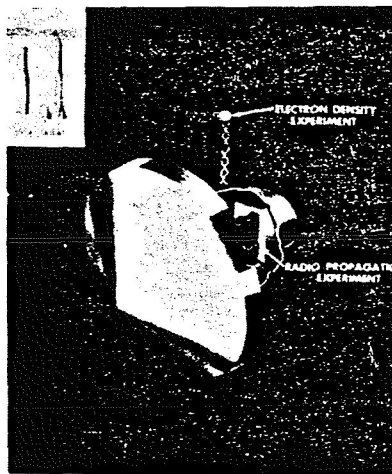


Fig. 4

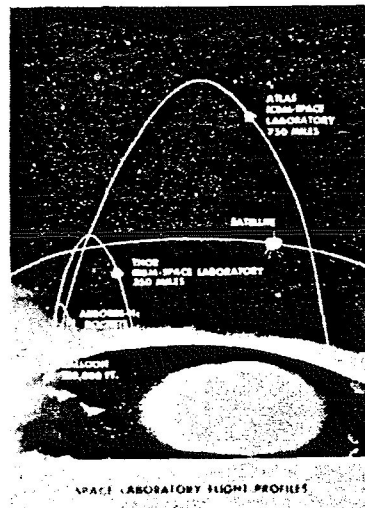


Fig. 5

An artist's conception of an earlier vehicle; Mark II, with space lab packages is given in Figs. 3 and 4. Typical flight profiles for ATLAS and THOR are shown in Fig. 5 together with the regions of space accessible to balloons and some earlier rockets.

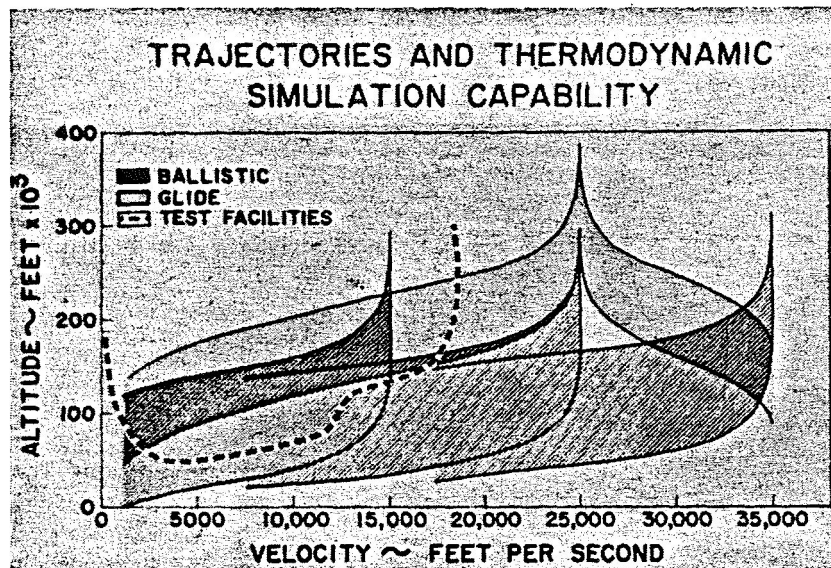


Fig. 6

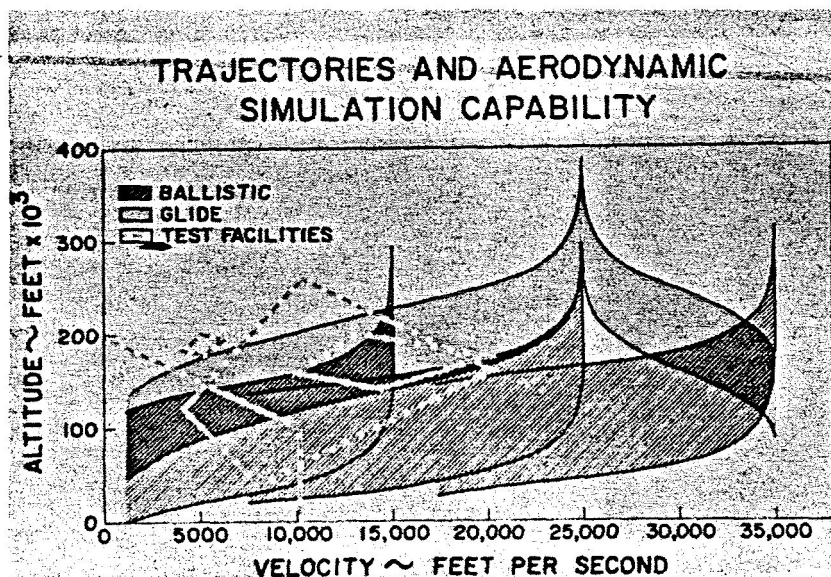


Fig. 7

The next two figures, 6 and 7 give some idea of the trajectories that are available.

Superimposed on Fig. 6 is a curve indicating the regions in which thermodynamic simulation has been achieved on the ground. The uniqueness of the flight facility is clearly shown.

In a similar fashion the aerodynamic simulation capability is superimposed on the trajectory curves in Fig. 7. The actual experiments that have been done are extremely diverse. In every case the details can be made available to properly qualified investigators. Brief summaries will be given here.

The result of the flight experiments can in general be divided into groups relating to:

1. Meteorology
2. Space Environment
3. Physiology
4. Hypersonic Aerodynamics
5. Communications
6. Materials and Structures
7. Hardware Development

The demonstration of the feasibility of using missile flights as a space laboratory is also one of the important products of this program.



Fig. 8

Meteorology

Some of the earliest and most spectacular Space Lab experiments were those involving photography of the earth and its cloud cover from several hundred miles in space. Figure 8 is a typical view which was selected because it shows nighttime on the part of the earth on the left hand side of the field, and day on the right side of the field.

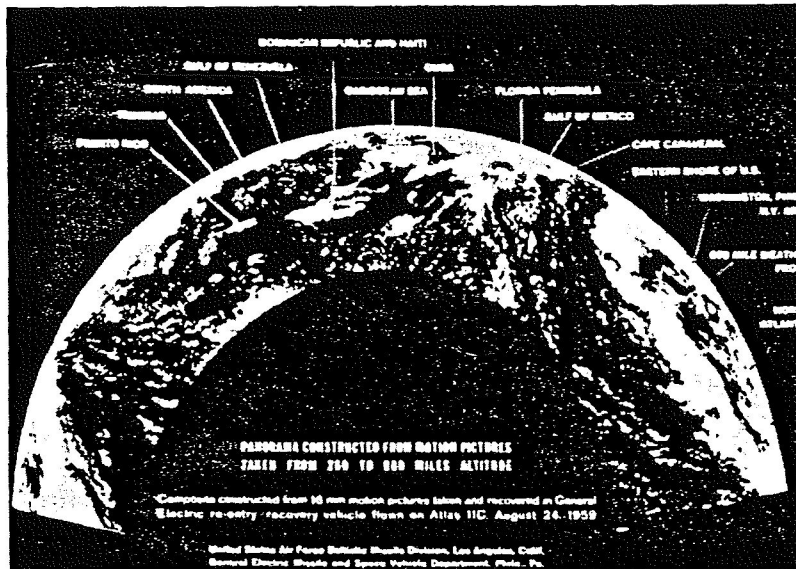


Fig. 9

Figure 9 is a mosaic made from sequential frames of a strip. This is a view which includes the coast of South America and the New York Area showing many interesting details of cloud formations. This picture was taken from an ATLAS flight on August 24th, 1959. It was shown first at an ARS meeting in Washington, D. C. in November, 1959, by D. N. Vachon and J. I. F. King (3).

The camera configurations, film selection and development techniques and meteorological data processing used in these experiments have guided subsequent studies from missiles and satellites. In addition to the cloud cover data, novel observations of the "texture" of the ocean surface revealed by its optical properties were made. Star photographs were also taken.

In one group of pictures, Fig. 10 a, b, c, and d the booster separation sequence was shown in detail.

The first camera was flown in the vehicle shown in Fig. 3.

A primary purpose of this flight was to demonstrate the capability of the Mark II vehicle to survive backward re-entry. For this purpose attitude sensing and control equipment was developed and installed. The function of the camera was primarily to monitor the vehicle attitude. The piggyback type of relationships of this meteorological experiment are clearly quite intricate.

Space Environment

Properties of the space environment of interest today are the nature and intensity of ionizing and electromagnetic radiation, the probability of encounters with meteorites of various sizes, the levels of the magnetic and



Fig. 10a



Fig. 10b



Fig. 10c



Fig. 10d

electric fields and the distribution and motion of charges. In each of these areas students are in a data gathering phase.

Several experiments were aimed at making observations on the radiation in the inner Van Allen belt. In view of the probability that solar activity influences the geometry of this belt, it is of the greatest importance to have

facilities for the systematic correlation of radiation data as a function of position and time. An electron spectrograph, an ion chamber, some radiation film badges and a variety of emulsion packages have been flown. These experiments have contributed to the mapping of space radiation. Some of the data have been reported by groups from Los Alamos (4) (12), Lawrence Radiation Laboratory (6) (7) and Air Force Cambridge Research Laboratory (8).

In connection with the detection of micro meteorites, five different types of sensors were flown. These included microphones, exposed fine wire grids, an aneroid type detector in which the pressure inside of a sealed box covered by a .006" plastic film was monitored, photoflash detectors and a retractable probe which exposed highly polished metal surfaces to the space environment. The sponsoring agency was Air Force Cambridge Research Laboratory (5) (9).

The only positive indication from these experiments in which more than 87 meter² sec. were exposed, was a period of less than 0.2 sec. in which all wire grid detectors saturated. The occurrence of showers or clouds of micro meteorites had been reported earlier from 1958 γ experiments and it has been confirmed more recently by some White Sands experiments featured in the science section of Time Magazine.

Measurements of the electric field in space and the potential of the vehicle with respect to its surroundings were also undertaken. A pair of generating voltmeters was flown on each of three vehicles. The data from one of these flights showed that fields due to charge on the vehicle increased with altitude and reached 300 volts/meter at peak altitude of 300 miles. The external electric field was found not to exceed 25 volts/meter. The charge on the vehicle was 5 to 10 times higher than had been predicted.

The same AFCRL group sponsoring the vehicle charge experiment also examined the ion and electron density as a function of altitude. The probes were shown in the drawing on Fig. 4. They consisted of spherical condensers, the outer electrode of which was perforated. The ion density found was reported by Dr. Rita Segalyn (10) (11).

Biological

One of the biological experiments that was flown piggyback was sponsored by the Air Force School of Aviation Medicine and the Air Force Special Weapons Center. Here an ion chamber and a package containing the well-known space mice Sally, Amy and Moe were exposed to the space and re-entry environment. We are happy to say that since their flight late in 1960 the mice seem to be enjoying a rich, full family life. The whitening of a few hairs in the coat of one of the mice was noted confirming some earlier observations on the effect of space radiation made in balloon flights. Respiration and heart performance records were made in flight and no pathologies were shown. The mice are shown in Fig. 11 with the package in which they flew. Notice that they were not constrained in the cage.

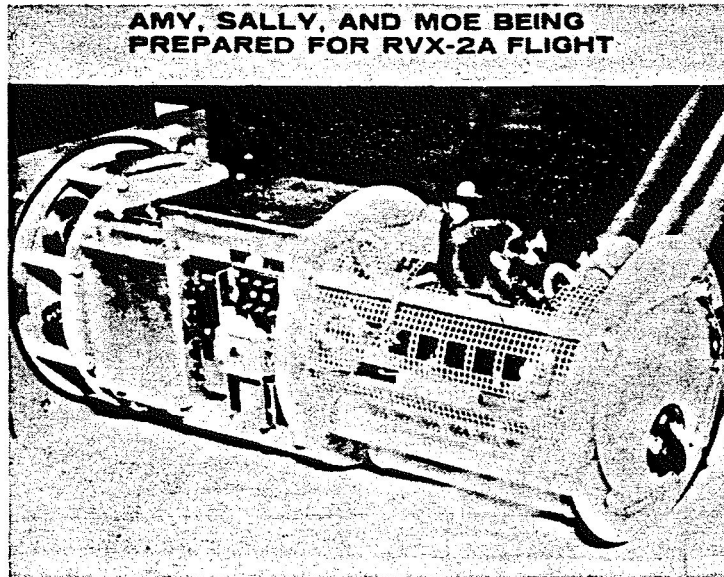


Fig. 11

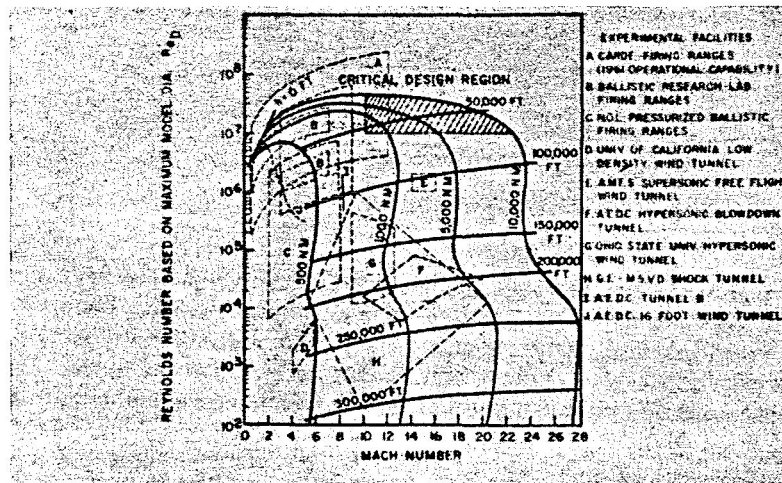


Fig. 12

Hypersonic Aerodynamics

Figure 12 shows again in a slightly different fashion the failure of ground facilities to simulate the range of Reynolds number and Mach number achieved in flight.

The shaded area where the loads on the vehicle are the highest is seen to be outside of the areas presently accessible in other types of experiment. Actually even for regions which can be covered on the ground the transient nature of the flow and the difficulty of precise definition of conditions tend to make the flight a superior facility.

By installing rate gyros, accelerometers, pressure ports, calorimeters and other sensors on a vehicle a substantial amount of aerodynamic data were obtained from the flights. For example it was shown that earlier theoretical and semi-empirical understanding of stability was not dependable when extrapolated to the hypersonic velocities associated with re-entry. The use of the flight data facilitated the evolution of the new techniques of flow field analysis which have been useful for design.

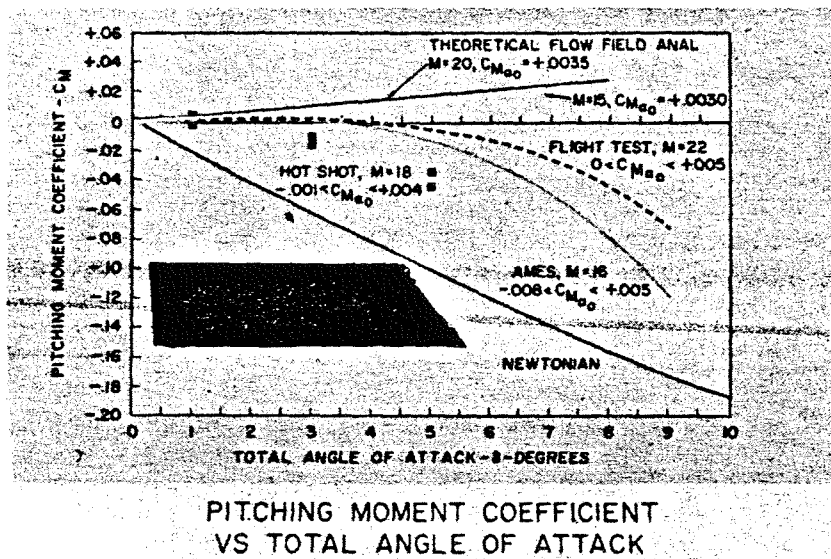


Fig. 13

Figure 13 is a plot of the theoretical and observed relationship between the moment coefficients and the angle of attack for a particular vehicle. The Newtonian approximation and early ground tests led to a prediction of stability. The flight test showed a region of instability which was confirmed by later ground tests and by new techniques of flow field analysis generated from flight data.

Heat transfer to various stations on the body and the state of ionization of the gas cap are also important aerodynamic considerations which were studied in flight. Many of the results of these experiments are reported in the classified literature but are not appropriate for this discussion. However, we can say that the flight data have had a profound effect on the design of heat shields and communication equipment that is now being used.

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The physical state of the gas around the body during re-entry was also revealed to some extent by studies of the distortion of a magnetic field produced by the flow. The possibility of using this magnetohydrodynamic effect in sensing and/or controlling devices still has vitality. The radiation generated in the incandescent gas cap was monitored in one interesting experiment, and some discrete lines were observed.

Communications

The opacity of the plasma generated by a re-entering vehicle to certain electro-magnetic radiation was anticipated and special provisions were made for obtaining continuous records from the instruments in the vehicle. However, the possibility of a continuous signal link is of technical interest and the nature of the interaction of the radiation and the plasma has scientific interest.

In one Space Lab experiment the reflections from the plasma as a function of frequency were observed. The time of high reflection, which coincided with signal blackout with VHF, was markedly less with HF. More must be done with vehicle and antenna configuration as well as with frequency selection to round out our understanding of the communications problem. Electro-magnetic observables also depend on signal-plasma interactions.

Materials and Structures

The lack of really adequate ground simulation makes the flight an indispensable facility for observing the behavior of thermal shield materials. Ablation sensors and inspection of the recovered vehicles are the devices used. While many of the extrapolations from ground facilities were found to be valid, for some materials and configurations the flight char retention was not as high as expected and erosion rates shown by the sensors and inspection of the recovered vehicle were correspondingly higher. This drew attention to the importance of the aerodynamic shear and noise levels encountered in flight.

Figure 14 is a picture of a core from a heat shield after re-entry. This enables you to see a more or less typical char layer that forms on an ablating heat shield material. This particular core also contains an ablation sensor plug which is wired to the telemetry system.

In connection with the design of control surfaces where the dimensional changes accompanying ablation might be a serious disadvantage, a patch of passive transpiration cooling system was flown. This consisted of a mesh of refractory metal with a piece of ablating, but non-charring plastic pressed against its back surface. This survived the flight adequately and showed clearly the reduction in surface temperature produced by transpiration.

Some of the vehicles contained noise and vibration sensors to indicate the mechanical climate generated in flight. The results were generally in agreement with expectations from analysis.

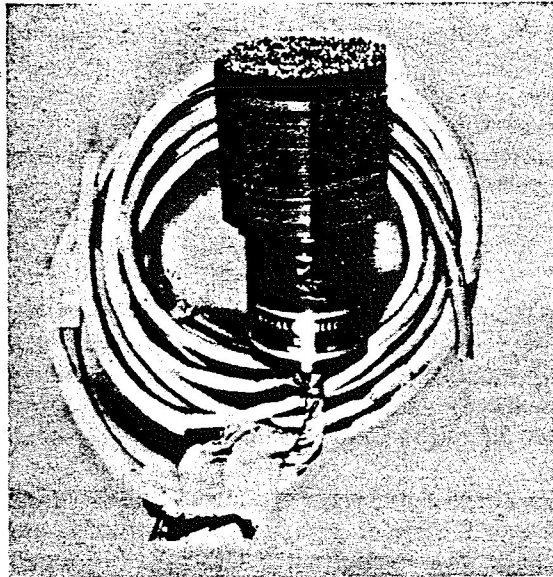


Fig. 14

Hardware Development

The translation of theoretical concepts and laboratory experiments into hardware is a popular source of vexation of engineers. In this program the problems are compounded by the novelty and severity of the environment. In reality, all of the attitude sensing and control devices, the accelerometers, the ablation and pressure sensors, the photographic equipment, the spectrographs, etc. aboard the vehicles are undergoing shakedown.

Some of the details of these pieces of hardware are discussed in Reference (2) which particularly emphasizes the prospect for the development of equipment for future satellite, lunar and interplanetary missions.

The behavior of a gas-liquid interface in the zero-g environment, the performance of a regenerative fuel cell and the generation of foamed plastic in space have also been the subject of experiments.

Conclusions

This has been a short verbal and pictorial tour through an experimental facility that has only recently become available. Some of you are likely to be able to use this facility in the future if you have not already done so. The results so far have been extremely useful and we look forward to more frequent flights, higher payload capabilities and a greater variety of trajectories becoming available. The mistakes that have been made do not have to be repeated and the sophistication of the experiments can be expected to increase. I am sure you do not have the impression that all of the worthwhile experiments have already been done.

As a terminal remark, the fact that it may be less expensive to do test work on a flight than on the ground is somewhat of a reversal of the old order of things. The piggyback or Space Laboratory program is largely responsible for this state of affairs.

Acknowledgements

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